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8 pages

## FINAL TECHNICAL REPORT

**(DURIP-97) SODIUM GUIDE STAR RAMAN LASER**

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## EXECUTIVE SUMMARY

This was an equipment grant funded under the Defense University Research Instrumentation Program (DURIP). The goal of this project was the acquisition of a critical piece of research equipment. In this case the equipment was a solid state, intracavity Raman laser for sodium guide star applications. Since no laser of this type is available as a commercial product, we collaborated with a local laser company, Lite Cycles, Inc., in the development of a prototype system. During the time of the grant, this was delivered and used for preliminary tests in our laboratory. The technology improvements necessary for a field version of the laser optimized for operation in an astronomical telescope were identified. The laser has now been transferred from our laser development laboratory to the astronomical adaptive optics group where it is being modified for practical applications as a guide star laser. This is a project funded by the Air Force.

## BACKGROUND

Adaptive optics is a rapidly developing technology for reducing the phase aberrations in an optical image due to atmospheric turbulence. The Air Force has been the lead agency in developing this technology due to its important applications in ground based telescope tracking stations and in air born laser systems. So far several lasers have been built to demonstrate the effectiveness of adaptive optics, but they do not have optimum characteristics for this application. Also, the exact requirements for an optimum sodium guide star laser transmitter are still a matter of controversy in the scientific community.

The University of Arizona has a *Center for Adaptive Optics* focused on developing all aspects of this technology. The primary funding for the Center comes from the Air Force. They have been relying on commercial dye lasers for their systems development. The purpose of this project was to engage the solid state laser development group in the Optical Sciences Center at the University of Arizona in developing a prototype solid state laser and defining the modifications necessary to optimize it for sodium guide star laser applications.

## DESCRIPTION OF THE PROJECT

The University of Arizona teamed with Lite Cycles, Inc., a small business in Tucson specializing in solid state lasers, to develop a unique solid state laser with a design that allows for future modifications of the system. This is a Raman laser pumped by a Nd-YAG laser and frequency doubled to obtain emission at the wavelength of the atomic transition of sodium. The initial system was flash-lamp pumped and Q-switched, but modified versions that are diode laser pumped and mode-locked have been produced.

The special coupled cavity design is shown in Fig. 1. The Nd-YAG cavity is a folded cavity with a dichroic mirror with high reflectors on both ends. The Nd-YAG

laser operates at  $1.064\ \mu\text{m}$  and none of the photons are allowed to escape the cavity. The entire lasing material is exposed to the pump light so that all pump photons are utilized. This results in a high Fresnel number, multi-mode output with very high operational efficiency. A Raman crystal is placed in the folded arm of this cavity. In order to achieve an output wavelength of  $1.1783\ \mu\text{m}$  a  $\text{CaWO}_4$  crystal is used. This arm of the pump laser cavity is shared with the Raman laser cavity with the end mirror acting as the high reflector. The Stokes shifted light passes through the dichroic turning mirror and hits an output coupler for the Raman laser. By focusing the pump laser appropriately into Raman crystal, the quantum conversion efficiency for the Raman process is limited only by the thermal defect and is close to 90%. The Raman laser cavity is designed as a single mode resonator. Because of the third order nonlinear optical processes associated with stimulated Raman scattering, automatic beam cleanup occurs and the beam quality of the emission is diffraction limited with the overall wall-plug efficiency of the system of about 10%. This output is then frequency doubled to achieve the required wavelength of 589.1 nm. To achieve maximum conversion efficiency, a system consisting of two counter-rotated phase plates between two LBO frequency-doubling crystals was used. It is important to note that optimum operational characteristics of high efficiency with diffraction limited astigmatic beam quality could only be obtained through detailed computerized laser design using program developed by this research team. The results are shown in Fig. 2.

Once the prototype laser was obtained, it was used in laboratory experiments to excite sodium gas in a cell with simulated temperature and pressure conditions of the upper atmosphere. Effects such as saturation were investigated for different laser pulse energies and repetition rates.

Two major problems were identified, optical damage in the Raman crystal and the lack of exact resonance between the laser and the sodium spectral line at upper atmospheric conditions. To try to solve these problems we worked with Scientific Materials, Inc. to modify both the pump and Raman laser materials. Through SBIR support, Scientific Materials has been able to alter the crystal growth parameters to produce ultra-pure  $\text{CaWO}_4$  with optical damage thresholds far above those of normal  $\text{CaWO}_4$ . This solved the first problem. To solve the second problem we tried to use compositionally tuned mixed garnet crystals for the pump laser. As shown in Fig. 3 (a), substituting a small amount of Ga ions for Y ions in the garnet host crystal shifts the lasing wavelength of the Nd ions. The appropriate mixed crystal should provide laser output at exactly the right wavelength to obtain resonance with the sodium transition. Although the crystals of this type grown by Scientific Materials did show the appropriate shift, the disorder introduced into the lattice produced significant inhomogeneous broadening and multi-line laser emission. This degraded the operating characteristics including efficiency and beam quality. A second method of tuning the output wavelength is to change the temperature of the laser material. Fig. 3 (b) shows the temperature dependence of the Nd-YAG laser transition as a function of temperature taken from the literature. By cooling the crystal to 230 K the required output wavelength can be obtained.

- Large Inversion Atom -to- Single Mode Photon Conversion Efficiency
- Wall-Plug Efficiency ~ 8-10 %
- Simple and Inexpensive

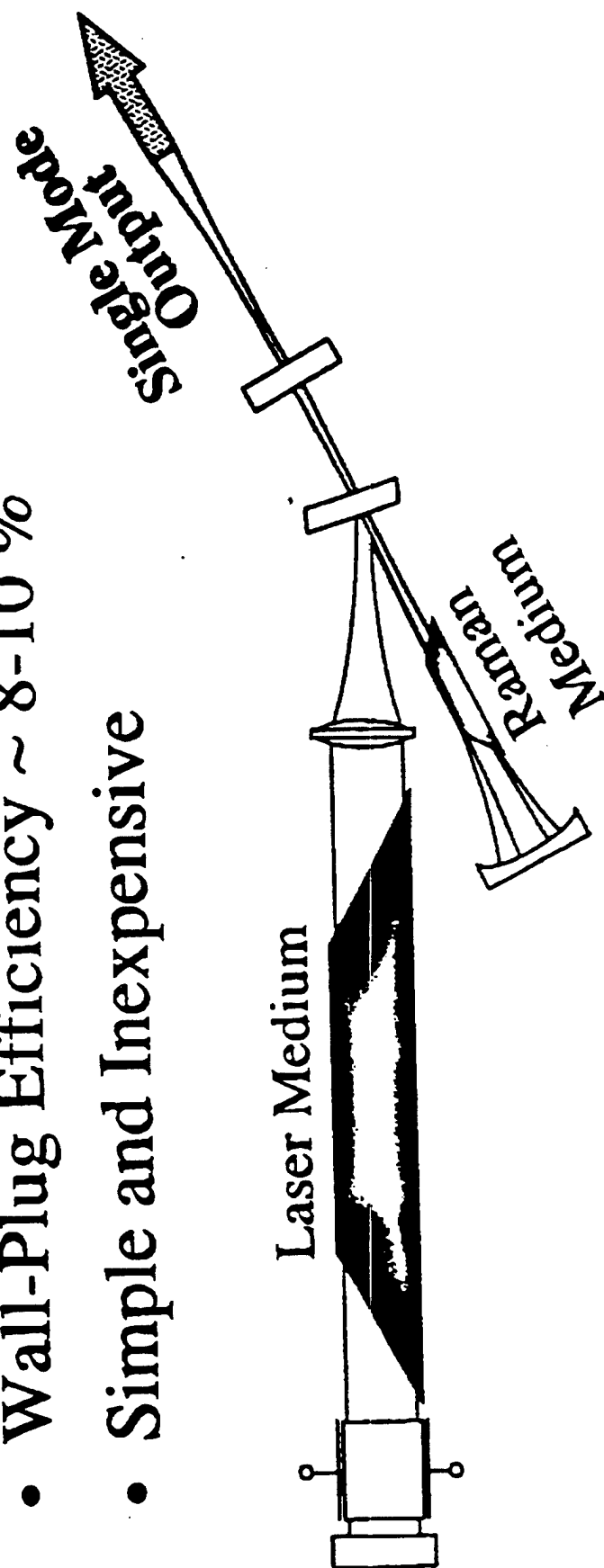
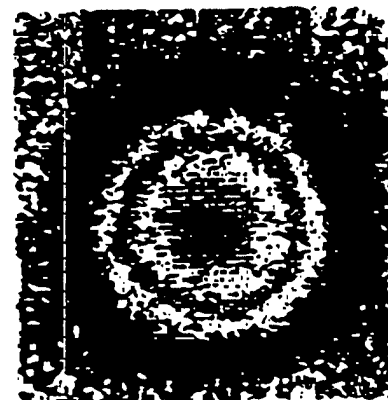
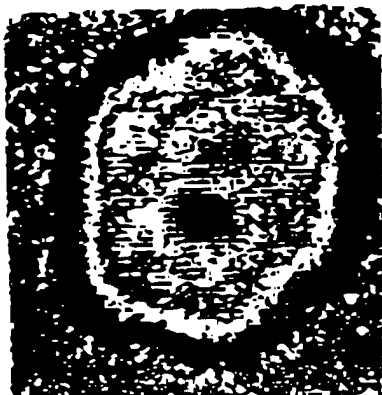


FIGURE 1: LASER CAVITY DESIGN

**FIGURE 2: LASER OUTPUT AND BEAM QUALITY****(A)****(B)**

(A) Spatial beam profile of the intracavity pump beam, and (B) the "cleaned-up" spatial beam profile of the output 1st Stokes beam. The 1st Stokes beam in these experiments was measured, within experimental error, to be diffraction-limited.



Photograph of the output of our laboratory prototype SSRS sodium guide star laser operating at 589.1 nm.

FIGURE 3(a)

# Compositionally Tuned $\text{Nd:Y}_3\text{Ga}_x\text{Al}_{5-x}\text{O}_{12}$ (YGAG)

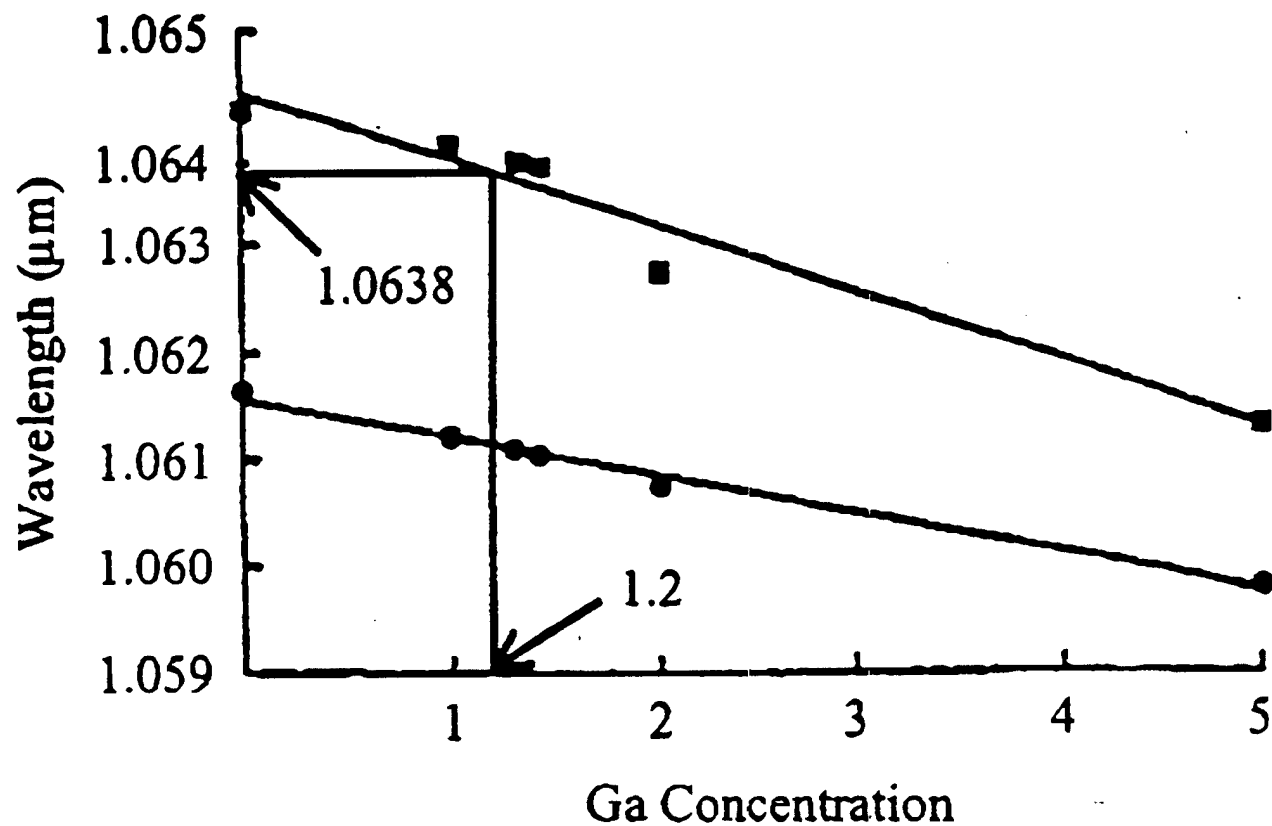
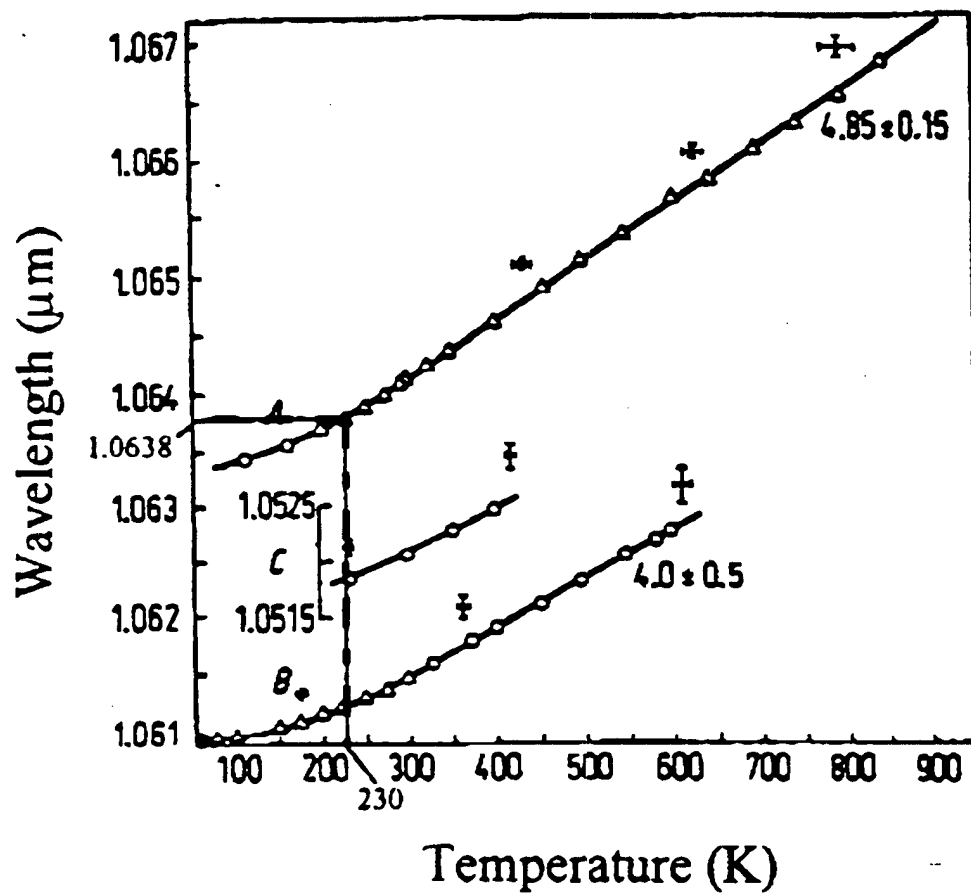


FIGURE 3(b)

# Temperature Tuned Nd:YAG



The laser has now been transferred to the group developing an adaptive optic system for the MMT telescope on Mt. Hopkins. They are working with a materials research group at the General Physics Institute in Moscow to try to identify a Raman crystal with exactly the right wavelength shift. If this is not successful they will either operate at cryogenic temperatures to obtain the exact wavelength or simply work off-resonance. The latter approach will provide a guide star that is not as bright as desired but acceptable for many applications. The solid state laser development is investigating new approaches using fiber lasers and color center lasers.



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